

The Conductivity and Ionization of Electrolytes in Aqueous Solutions as Conditioned by Temperature, Dilution and Hydrolysis.

DISSERTATION

SUBMITTED TO THE BOARD OF UNIVERSITY STUDIES OF
THE JOHNS HOPKINS UNIVERSITY IN CONFORMITY
WITH THE REQUIREMENTS FOR THE DEGREE
OF DOCTOR OF PHILOSOPHY.

BY

CARL ALFRED JACOBSON.

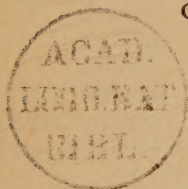
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The Conductivity and Ionization of Electrolytes in Aqueous Solutions as Conditioned by Temperature, Dilution and Hydrolysis.

Introduction.

It is now generally recognized that chemical activity is conditioned primarily by the number of reacting parts or ions. Therefore, any method by which the number of ions can be determined or, in other words, any method that gives the percentage dissociation of a compound, is of fundamental importance. Of the three or four methods now in use for determining ionization, the electrical conductivity method is doubtless the most general, and in all probability the most reliable.

That the conductivity of electrolytes is influenced by temperature has been known for about fifty years.

Beetz,¹ in 1862, was the first to arrive at any definite relation between temperature and conductivity, although Hankel,² Marie-Davy,³ Becquerel,⁴ and a few others had previously made some observations which led them to conclude that the conductivity of electrolytes increases with rise in tempera-

¹ Pogg. Ann., **117**, 1 (1862).

² *Ibid.*, **69**, 255 (1846).

³ Compt. rend., **54**, 465.

⁴ Pogg. Ann., **70**, 254 (1847).

ture. Beetz worked with zinc sulphate from 1° to 24° , at various concentrations, and arrived at the formula

$$Z = 32.09 + 4.0346p - 0.04073p^2$$

as expressing the relation between temperature and conductivity. (p is the percentage concentration of anhydrous zinc sulphate). He thus concluded that the conductivity increases proportionally with rise in temperature, except at high dilutions. Beetz also observed a maximum in the conductivity curve, with changing concentration, and noticed that this maximum varied with change in temperature. In 1879 Freund¹ repeated the experiments of Beetz and found the same relations to hold, but his results were about 5 per cent higher. Other investigators in this field are: Berggren,² Lentz,³ and Sack.⁴ The last-named found a sharp maximum conductivity in three different concentrations of copper sulphate.

Grotrian,⁵ in 1874, investigated the effect of temperature on the conductivity of sulphuric and hydrochloric acids, from 8° to 70° , at different dilutions, and concluded that conductivity is a linear function of the temperature. The following year Kohlrausch and Grotrian⁶ made a comprehensive study of this field, using numerous salts and acids at temperatures ranging between 0° and 40° , and deduced the following formula as expressing the relation between temperature and conductivity:

$$K_t = K_0(1 + \alpha t + \beta t^2),$$

in which K represents the conductivity, t the temperature, α and β constants of different orders of magnitude, as found by experiment. They calculated the temperature coefficients at 18° by the equation

$$\left(\frac{1}{K} \frac{dK}{dt}\right)_{18} = \frac{\alpha + 2\beta.18}{1 + \alpha.18 + \beta.18^2},$$

¹ Wied. Ann., **7**, 49 (1879).

² *Ibid.*, **1**, 499 (1877).

³ Bull. Acad. Imp. Sci., St. Petersburg., **10**, 299.

⁴ Wied. Ann., **43**, 212 (1891).

⁵ Pogg. Ann., **151**, 378 (1874).

⁶ *Ibid.*, **154**, 215 (1875).

in which the symbols have the same meaning as above. From this work they concluded that the conductivity of dilute solutions is not a linear function of the temperature, as was originally thought, but a *parabolic one*. They also observed a maximum conductivity for hydrochloric acid when the concentration was about 30 per cent. In 1885 Kohlrausch¹ represented conductivity graphically as the cube root of the concentration. In other words, he made μ_v the ordinate and $\sqrt[3]{1/v}$ the abscissa.

Up to this time no exception had been found to the general principle that the conductivity of electrolytes in aqueous solution increases with rise in temperature, and also with increase in dilution where the concentration is less than 0.1 normal. Arrhenius,² in 1889, was the first to notice an exception. He found that the conductivity of phosphoric and hypophosphorous acids decreases with rise in temperature, between 25° and 95°. Sack³ and others have since observed negative temperature coefficients, but more especially with organic solvents. The explanation hitherto offered for the rapid increase in conductivity with rise in temperature is that dissociation increases as the temperature increases. In other words, the higher the temperature the larger the number of ions present for a given concentration and, consequently a resulting increase in conductivity. The fact that Arrhenius found a diminishing dissociation with rise in temperature led others to work along this line.

In 1890 Krannhals⁴ took up the problem and measured the conductivity of a number of acids and salts at the following temperatures: 18°, 50°.3, 82°, and 99°.4. He found that the conductivity increases as a linear function of the dilution, and a parabolic function of the temperature, except for magnesium sulphate and potassium ferrocyanide, where the increase is abnormally great. The reason for this increase in conductivity with rise in temperature he ascribed to diminishing viscosity of the solvent. In some cases he

¹ Wied. Ann., 26, 197 (1885).

² Z. physik. Chem. 4, 96 (1889).

³ Loc. cit.

⁴ Z. physik. Chem., 5, 250 (1890).

observed a decrease in dissociation with rise in temperature, but concluded that this must be due to experimental error.

The same year J. Trötsch¹ undertook an investigation to ascertain the influence of water of crystallization on the conductivity of electrolytes, and arrived at the conclusion that the conductivity of those substances which do not crystallize with water increases regularly or remains constant with rise in temperature, while in the case of those substances that crystallize with water, the rate of increase of conductivity grows less as the temperature rises, as well as with increase in dilution. He also noticed that the temperature coefficients of cupric chloride, at all concentrations, increase from 0° to 40°, and then decrease. He noticed a sudden change in color from green to blue in an 18.2 per cent solution of cupric chloride, and from red to blue at different concentrations of cobalt chloride above 100°. He explained these phenomena as being due to a loss of the water of hydration. He also concluded, as many before him had done, that increase in temperature increases the dissociation.

In 1891 Douglas² worked with several acids, bases, and salts at temperatures ranging from 0° to 35°. From his work he drew the conclusion that dissociation is independent of temperature. The same conclusion was reached by Wood³ and Jahn,⁴ although the results of the former indicate just the opposite. Jahn, however, admitted that his results, in the case of valeric acid, showed a diminishing dissociation with rise in temperature, but thought that this was probably due to experimental error.

In 1900 Whetham⁵ determined the ionization of a few strongly dissociated acids and salts at 0° by the freezing point method. After comparing his results with those of Kohlrausch, he concluded that the dissociation is greater at 0° than at 18°.

¹ Wied. Ann., **41**, 259 (1890).

² Am. Chem. Jour., **26**, 428 (1891).

³ Phil. Mag., **41**, 117 (1896).

⁴ Z. physik. Chem., **18**, 72 (1895).

⁵ *Ibid.*, **33**, 344 (1900).

The more recent investigations of Euler,¹ Schaller,² Noyes,³ and West,⁴ however, all point to the conclusion that dissociation diminishes with rise in temperature. Euler worked with a number of organic acids at eight temperatures ranging between 0° and 50°. Schaller studied organic acids and salts at temperatures ranging between 25° and 99°. In addition to observing that dissociation decreases with rise in temperature, he noticed that when the electrolytes are completely dissociated, the increase in conductivity is very nearly a linear function of the temperature. This was contrary to the observation of Kohlrausch and Grotrian referred to above.

An enormous amount of conductivity work has been done besides that already mentioned, but no reference will be made to work carried out at only one temperature, or where solvents other than water have been used, since that would not properly come within the scope of this paper.

We may summarize the results hitherto obtained as follows:

- (1) The conductivity increases with rise in temperature.
- (2) Conductivity increases with increase in dilution.
- (3) Dissociation increases with increase in dilution.

Considering the number of conflicting results on the following points, we are inclined to believe that further confirmatory evidence is necessary before they are fully established:

- (1) Dissociation decreases with rise in temperature.
- (2) Conductivity is a linear function of the temperature.
- (3) Conductivity is a cube root function of the concentration.

Some time after the publication of West's work, Jones⁵ pointed out certain relations existing between the temperature coefficients of electrolytes and their hydrating power. Using West's results he showed that those electrolytes with no hydrating power have smaller temperature coefficients than those with large hydrating power, and that the order

¹ Z. physik. Chem., **21**, 257 (1896).

² *Ibid.*, **25**, 497 (1898).

³ J. Am. Chem. Soc., **26**, 134 (1904).

⁴ Am. Chem. Jour., **34**, 357 (1905).

⁵ *Ibid.*, **35**, 445 (1905).

of the temperature coefficients will, in a measure, determine the hydrating power of the electrolyte. The close relation existing between the water of hydration and water of crystallization of a compound is seen from the work of Jones and his students.¹

Purpose of this Investigation.

From the brief historical sketch here given, it is seen that the conclusions drawn regarding the influence of temperature upon dissociation are conflicting, and that they need further experimental verification before they can be considered as fully established. The present work was undertaken to supply some such evidence; and further, to extend the investigation to a larger number of inorganic compounds than was done by West, as well as to include some typical organic acids, to test the relations pointed out by Jones² between the temperature coefficients of conductivity of electrolytes and their hydrating power.

Method Employed.

The present work is, broadly speaking, a continuation of that by Jones and West,³ and the method is essentially the same as the one that they employed.

Apparatus.—Eight conductivity cells of the form used in this laboratory were employed. The conductivities were read at eight concentrations, ranging from $N/2$ to $N/2048$, according to the Ostwald scheme of dilution. One cell was employed for each dilution.

The well-known Kohlrausch method, consisting of a Wheatstone bridge, resistance box, telephone, and an induction coil supplying the alternating current, was employed for reading the conductivities. The calibration of the bridge wire, resistance box, and thermometers was done in essentially the same way as that described by Jones and West. Moreover, it was considered advisable to keep the same range of temperature as they did, namely 0° , 10° , 25° and 35° .

¹ Carnegie Monograph No. 60 (Hydrates in Solution), 1906.

² Am. Chem. Jour., **35**, 445 (1905).

³ *Ibid.*, **34**, 357 (1905).

In order to bring the cells containing the solutions to these temperatures, constant-temperature water baths were employed. I found that the zero bath described by West

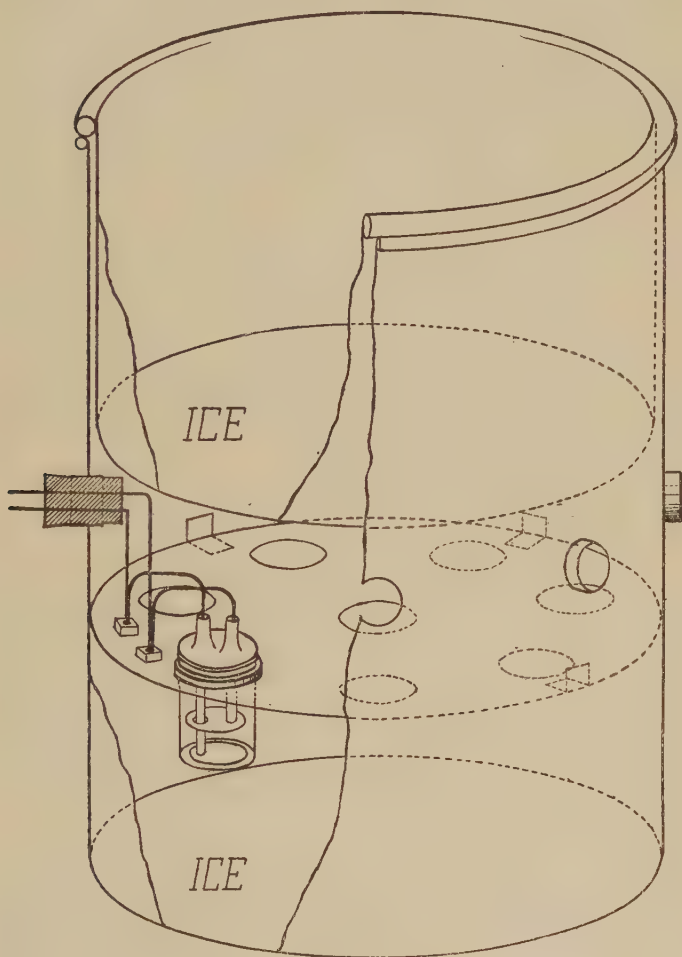


Fig. I.

gave conductivities that were invariably too high by about 0.5 per cent, and the difficulty was thought to lie in the fact that the upper portion of the cell was exposed to a much

higher temperature, and, consequently, heat would be conducted into the solution, especially by the mercury of the electrodes. To overcome this difficulty, I constructed another form of ice bath, shown in the accompanying cut, Fig. I. By this means the air above and in immediate contact with the cells could also be brought to zero temperature. The whole apparatus was surrounded by hair packing, and well protected against conduction of heat from surrounding objects. This form of ice bath gave entirely satisfactory results.

The temperature of the 10° bath was regulated by a small gas burner and running hydrant water, stirred by a hot-air engine. I found that the temperature of the hydrant water did not remain constant long enough to answer the purpose without this regulation. Instead of using the Ostwald thermostat for the 25° and 35° baths, as was done by West, I obtained better results by simply regulating the flame of a small gas burner by hand. The water in these two baths was also stirred as above indicated.

The burettes and measuring flasks were calibrated for 20° by weighings reduced to the vacuum standard.

Water.—The conductivity water employed in this laboratory¹ was used in preparing the solutions. In order to obtain the true value for the conductivity of the electrolyte, a correction term must, of course, be applied for the conductivity of the solvent. Where the dilution is high this correction has a considerable value. The temperature coefficients of conductivity of water are also large, and this fact must be taken into account wherever conductivities are read at more than one temperature.

Although the marked influence of temperature on the conductivity of water had been pointed out by Pfeiffer,² Kohlrausch,³ and Schaller,⁴ yet very few of the experimenters working in this field state that this fact was taken into account

¹ Am. Chem. Jour., **19**, 91 (1897).

² Wied. Ann., **31**, 831.

³ Z. physik. Chem., **14**, 324 (1894).

⁴ *Ibid.*, **25**, 497 (1898).

Euler¹ gives his reason for not applying the correction for water. Kohlrausch and Heydweiller found that the increase in the conductivity of water with rise in temperature was more rapid at higher than at lower temperatures. Schaller's results indicate a linear relation between conductivity and temperature from 25° to 99°. The latter relation has been found to hold in my work with numerous samples of water. A few of the results obtained with water investigated during the progress of this work are plotted in the accompanying diagram, where temperatures are the abscissae, and conductivities $\times 10^{-6}$ the ordinates.

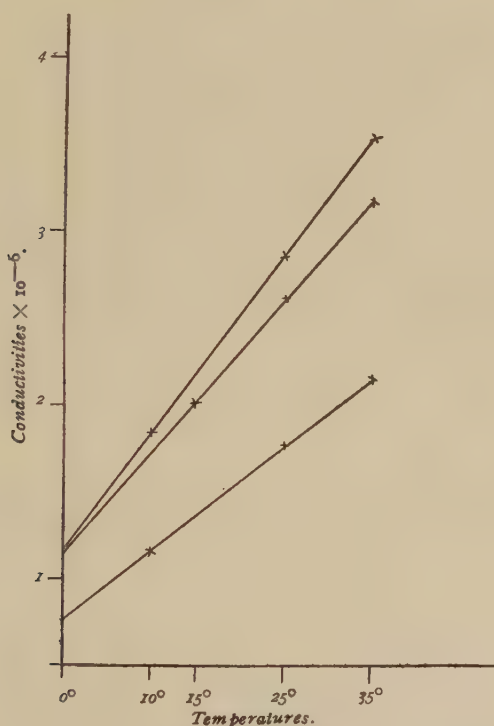


Fig. II.

Solutions.—The purest obtainable materials were used in the preparation of the solutions. However, before the

Loc. cit.

salts were used they were carefully tested for impurities, and in most cases recrystallized one or more times. Except in a few cases, where the compounds are stable in the air, the solutions were all standardized by analysis. The organic acids, the purity of which had first been tested by determining their melting points, were standardized volumetrically with an aqueous solution of potassium hydroxide, which had been especially prepared and purified. The solutions were then made up by diluting the more concentrated with water, and bringing them to the calibration temperature.

Cell Constants.—For determining the cell constants, I took ($129.7 + \mu$ for water) as the conductivity of a N/50 solution of potassium chloride at 25° as the basis of my calculations. The purest obtainable potassium chloride was tested and further purified by fractional crystallization before it was used in the preparation of the above-mentioned standard solution. With this solution the cell constants of the first four cells were determined. Then a N/500 solution was prepared from the N/50 and its conductivity found by using the four cells whose constants had been determined. The value thus obtained for μ of the more dilute solution was used in determining the cell constants of the remaining four cells. The cell constants were redetermined every three or four weeks throughout the year. Ordinarily, no change in the cell constants amounting to more than 0.2 to 0.3 per cent was found.

For the purpose of checking the cell constants at 0° , I determined the following values of μ for potassium chloride: N/500 at $25^\circ = 137.7$, N/50 at $0^\circ = 71.45$, N/500 at $0^\circ = 75.63$. These are the averages of a large number of determinations, none of which varied more than 0.5 per cent from the others. To obtain the true values for any one of these solutions, the proper value for μ of water must be added.

Units.—To be consistent with the work previously done in this laboratory the results are expressed in Siemens units, and all conductivities here referred to are molecular conductivities—gram-molecular weights having been used in making up the solutions.

Results.—The results are expressed in the following tables. The molecular conductivities (μ_v) at the four temperatures indicated were calculated from the equation

$$\mu_v = K \frac{Va}{Rb}$$

where K is the cell constant, V the volume concentration, R the resistance, a and b the two arms of the bridge. The percentage dissociation (α) was calculated from the equation

$$\alpha = \frac{100 \cdot \mu_v}{\mu_\infty},$$

where μ_∞ is the conductivity at complete dissociation, or the highest value for μ_v obtained for the strongly dissociated electrolytes in which no hydrolysis is known to have taken place. When hydrolysis did take place, as for example, with ferric chloride, as well as in the case of the weakly dissociated organic acids, α was calculated from Kohlrausch's law, $\mu_\infty = c + a$, where c and a represent the velocities of the cation and anion, respectively. The temperature coefficients, expressed in conductivity units between the temperatures indicated, were calculated from the formula

$$\frac{(\mu_v)_{t_1} - (\mu_v)_t}{t_1 - t},$$

in which $(\mu_v)_{t_1}$ represents μ_v at the higher temperature (t_1) and $(\mu_v)_t$ at the lower temperature (t), while the same coefficients expressed in percentages were calculated from the formula

$$\frac{(\mu_v)_{t_1} - (\mu_v)_t}{t_1 - t} \times \frac{100}{(\mu_v)_t}.$$

For each conductivity measurement given in the tables, three readings were taken, changing the resistance in the resistance box so as to bring the node on the bridge as near to the 40, 50, and 60 cm. marks as practicable. The mean of these was taken as the final reading. Whenever any ir-

regularities appeared, either in the conductivities or in the temperature coefficients, the same readings were repeated one or more times on following days.

Sources of Error.

It may be well to call attention to some of the more important sources of error that must be taken into account in all conductivity work. In the first place, a sharp minimum in the telephone is not secured unless the electrodes are clean and well covered by a layer of platinum black or "platinum white." A small amount of an oily constituent is present in ordinary distilled water, and where the electrodes are left overnight in such water a small residue will be left on them, as is often seen deposited on the inside walls of wash-bottles, etc. It may take weeks before this becomes perceptible, but it should be taken into account.

At temperatures above 25° air bubbles are often found to gather on the electrodes, as has been pointed out by Jones and West. These not only interfere with the minimum in the telephone but may also affect the conductivity. After trying various methods for obviating this difficulty I found that the most satisfactory one was to heat the bath a few degrees above the temperature at which the conductivities are to be read, and after the bubbles have collected for a time, to raise the electrodes out of the solution, then returning them at once and cooling down the bath to the required temperature. When this is done the cells may be kept for any desired length of time at the temperature in question without any sign of a bubble appearing.

Another source of error often arises in assuming that the cells have attained the temperature of the bath before they have actually done so.

When small resistances are to be measured it is of the utmost importance to have the plugs in the resistance box absolutely clean, since a very small quantity of foreign matter on each plug will accumulate on the small resistance read, and will often amount to several per cent.

When working at temperatures above that of the room, a source of error that must not be overlooked is the condensation of the solvent on the glass stopper of the cell, thus concentrating the solution.

A formidable source of error is found in hydrolysis taking place to a greater or less extent in dilute solutions. This, of course, increases the conductivity to an enormous extent, as is seen especially in the case of iron salts. For this reason it becomes impossible to find μ_{∞} for such compounds by the conductivity method directly, and the true value of μ_{∞} for other electrolytes is called into question, since we are unable to tell to what extent hydrolysis has taken place.

Lithium Chloride.

Table I.—Molecular Conductivity and Dissociation.

V.	0°.		11° 2.		25°.		35°.	
	μ_v .	α .	μ_v .	α .	μ_v .	α .	μ_v .	α .
2	41.33	72.1	55.26	70.3	75.79	68.7	91.71	68.5
8	47.27	82.4	64.18	81.6	88.41	80.1	105.9	79.1
16	49.20	85.8	67.33	85.6	92.89	85.1	112.3	83.9
32	51.11	89.1	69.91	88.9	96.24	87.2	116.4	86.9
128	53.96	94.1	73.92	94.0	101.5	91.9	122.9	91.8
512	55.55	96.9	77.52	97.0	106.3	96.6	128.6	96.0
1024	56.08	97.8	77.62	98.7	107.2	97.1	130.3	97.3
2048	57.34	100.0	78.64	100.0	110.4	100.0	133.9	100.0

Table III.—Temperature Coefficients.

V.	0° to 11° 2.		11° 2 to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
2	1.24	3.00	1.49	2.69	1.59	2.10
8	1.51	3.41	1.75	2.72	1.75	1.98
16	1.62	3.39	1.85	2.75	1.94	2.09
32	1.68	3.29	1.91	2.73	2.02	2.10
128	1.79	3.32	2.00	2.70	2.14	2.11
512	1.90	3.42	2.08	2.69	2.23	2.10
1024	1.92	3.42	2.15	2.77	2.31	2.15
2048			2.28	2.90	2.35	2.13

*Lithium Bromide.**Table IV.—Molecular Conductivity.*

V.	0°.	9°3.	25°.	35°.
2	44.83	55.94	78.52	96.02
8	49.84	63.42	89.78	109.5
16	51.51	66.75	95.03	114.9
32	53.10	68.77	98.66	119.5
128	56.57	73.70	106.7	128.6
512	57.44	75.06	108.2	130.6
1024	57.97	75.99	109.9	133.3
2048	61.05	80.68	114.8	138.3

Table V.—Percentage Dissociation.

V.	0°.	9°3.	25°.	35°.
2	73.4	69.3	68.4	69.4
8	81.6	78.6	78.2	79.2
16	84.4	82.7	82.8	83.1
32	87.0	85.2	85.9	86.4
128	92.7	91.4	92.9	93.0
512	94.1	93.0	94.3	94.4
1024	95.0	94.2	95.7	96.4
2048	100.0	100.0	100.0	100.0

Table VI.—Temperature Coefficients.

V.	0° to 9°3.		9°3 to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
2	1.19	2.66	1.43	2.56	1.75	2.23
8	1.46	2.93	1.67	2.63	1.97	2.19
16	1.63	3.16	1.80	2.70	1.99	2.09
32	1.68	3.16	1.90	2.91	2.08	2.11
128	1.84	3.25	2.10	2.85	2.19	2.05
512	1.89	3.29	2.11	2.81	2.24	2.07
1024	1.94	3.35	2.16	2.84	2.34	2.13
2048	2.33	3.82	2.17	2.68	2.35	2.05

*Lithium Nitrate.**Table VII.—Molecular Conductivity.*

V.	0°.	10°.	25°.	35°.
2	38.65	52.28	70.56	82.20
8	43.83	57.79	79.71	96.99
16	45.96	60.32	84.16	100.9
32	47.27	62.51	87.39	105.1
128	51.05	66.88	93.29	112.2
512	51.53	68.07	96.03	115.6
1024	52.00	69.47	98.01	117.8
2048	52.40	70.01	100.03	121.0

Table VIII.—Percentage Dissociation.

V.	0°.	10°.	25°.	35°.
2	73.8	74.7	70.4	67.9
8	83.6	82.5	79.5	80.2
16	87.7	86.2	83.9	83.4
32	90.2	89.3	87.1	86.9
128	97.4	95.5	93.0	92.7
512	98.3	97.2	95.7	95.5
1024	99.2	99.2	97.7	97.4
2048	100.0	100.0	100.0	100.0

Table IX.—Temperature Coefficients.

V.	0° to 10°.		10° to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
2	1.26	3.26	1.35	2.58	1.64	2.32
8	1.40	3.19	1.46	2.53	1.67	2.09
16	1.44	3.13	1.59	2.64	1.70	2.02
32	1.52	3.22	1.66	2.67	1.77	2.03
128	1.58	3.10	1.76	2.63	1.89	2.03
512	1.65	3.20	1.86	2.73	1.96	2.04
1024	1.75	3.36	1.90	2.73	1.98	2.02
2048	1.76	3.36	2.02	2.89	2.07	2.06

*Lithium Sulphate.**Table X.—Molecular Conductivity.*

V.	0°.	9°6.	25°.	35°.
2	47.08	61.97	89.59	107.5
8	66.74	88.18	128.4	154.9
16	75.50	100.2	144.5	175.3
32	82.15	109.5	159.3	194.0
128	96.81	129.0	188.5	230.3
512	104.6	139.1	202.8	248.3
1024	108.1	143.8	211.4	258.8
2048	111.8	148.0	219.5	268.0

Table XI.—Percentage Dissociation.

V.	0°.	9°6.	25°.	35°.
2	42.1	41.9	40.8	40.1
8	59.7	59.6	58.5	57.8
16	67.5	67.7	65.8	65.4
32	73.5	74.0	72.6	72.4
128	86.6	87.2	85.9	85.9
512	93.8	94.0	92.4	92.7
1024	96.7	97.2	96.3	96.6
2048	100.0	100.0	100.0	100.0

Table XII.—Temperature Coefficients.

V.	0° to 9°6.		9°6 to 25°.		25° to 35°.	
	Cond. units.	Percent.	Cond. units.	Percent.	Cond. units.	Per cent.
2	1.55	3.29	1.68	2.71	1.79	2.00
8	2.23	3.34	2.25	2.55	2.65	2.06
16	2.57	3.40	2.88	2.87	3.08	2.13
32	2.85	3.47	3.23	2.96	3.47	2.18
128	3.35	3.46	3.86	2.99	4.18	2.22
512	3.59	3.43	4.14	2.98	4.55	2.25
1024	3.72	3.41	4.39	3.05	4.74	2.24
2048	3.77	3.37	4.64	3.13	4.85	2.21

*Sodium Nitrate.**Table XIII.—Molecular Conductivity and Percentage Dissociation.*

V.	0°.		25°.		35°.	
	$\mu_{v.}$	$\alpha.$	$\mu_{v.}$	$\alpha.$	$\mu_{v.}$	$\alpha.$
2	43.34	72.3	78.1	67.0	91.7	65.0
8	50.27	83.9	90.9	77.9	111.3	78.9
16	52.57	86.1	97.5	83.6	117.5	83.3
32	55.38	92.4	101.3	86.9	122.5	86.9
128	59.28	98.9	107.7	92.3	128.9	91.4
512	59.34	99.0	111.3	95.5	134.8	95.6
1024	59.39	99.8	114.0	97.8	138.5	98.2
2048	59.93	100.0	116.6	100.0	141.0	100.0

Table XIV.—Temperature Coefficients.

V.	0° to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.
2	1.39	3.21	1.36	1.74
8	1.62	3.22	2.04	2.24
16	1.79	3.41	2.00	2.44
32	1.83	3.30	2.12	2.05
128	1.94	3.27	2.12	1.94
512	2.08	3.51	2.35	2.11
1024	2.18	3.68	2.45	2.15
2048	2.27	3.79	2.44	2.09

*Disodium Phosphate.**Table XV.—Molecular Conductivity and Percentage Dissociation.*

V.	0°.		25°.		30°.	
	μ_v .	α .	μ_v .	α .	μ_v .	α .
16	67.3	68.8	133.4	72.5	148.6	72.1
32	75.0	81.5	147.8	80.3	164.5	79.8
128	88.4	96.1	168.6	91.5	188.1	91.2
512	91.7	99.7	182.3	99.1	203.8	98.8
1024	91.9	99.9	183.7	99.8	205.2	99.5
2048	92.0	100.0	184.0	100.0	206.2	100.0

Table XVI.—Temperature Coefficients.

V.	0° to 25°.		25° to 30°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.
16	2.64	4.17	3.04	2.28
32	2.91	3.88	3.34	2.26
128	3.21	3.63	3.90	2.32
512	3.62	3.95	4.30	2.35
1024	3.67	3.99	4.30	2.34
2048	3.68	4.00	4.44	2.41

*Potassium Sulphocyanate.**Table XVII.—Molecular Conductivity.*

V.	0°.	13°·5.	25°.	30°.
2	57·75	79·47	100·0	110·2
8	62·48	87·87	110·9	121·9
16	64·26	90·81	115·4	126·8
32	65·99	93·39	118·7	130·8
128	70·70	100·1	127·3	139·4
512	71·28	101·2	129·8	142·3
1024	72·25	102·6	131·5	144·3
2048	72·86	103·0	133·7	147·3

Table XVIII.—Percentage Dissociation.

V.	0°.	13°·5.	25°.	30°.
2	79·3	77·2	74·8	74·8
8	85·8	85·3	83·0	82·8
16	88·2	88·2	86·3	86·1
32	90·6	90·7	88·8	88·8
128	97·0	97·2	95·2	94·6
512	97·8	98·3	97·1	96·6
1024	99·2	99·6	98·4	98·0
2048	100·0	100·0	100·0	100·0

Table XIX.—Temperature Coefficients.

V.	0° to 13°·5.		13°·5 to 25°.		25° to 30°.	
	Cond. units.	Percent.	Cond. units.	Percent.	Cond. units.	Percent.
2	1·31	2·27	1·78	2·24	2·04	2·04
8	1·88	3·00	2·00	2·28	2·20	1·98
16	1·97	3·07	2·14	2·36	2·28	1·98
32	2·04	3·09	2·18	2·33	2·41	2·03
128	2·18	3·08	2·38	2·38	2·42	1·90
512	2·23	3·13	2·46	2·43	2·50	1·93
1024	2·26	3·13	2·49	2·43	2·56	1·95
2048	2·24	3·07	2·60	2·52	2·72	2·03

*Potassium Chromate.**Table XX.—Molecular Conductivity.*

V.	0°.	12°. ₂ .	25°.	35°.
2	96.50	128.1	165.7	197.5
8	111.3	151.9	196.0	235.4
16	117.8	163.5	213.5	256.0
32	124.6	173.7	227.2	272.0
128	140.1	191.1	252.9	303.0
512	147.1	205.5	272.0	327.8
1024	150.1	209.2	276.2	330.2
2048	151.4	211.5	279.9	334.3

Table XXI.—Percentage Dissociation.

V.	0°.	12°. ₂ .	25°.	35°.
2	63.7	60.6	59.2	59.6
8	73.5	71.8	70.0	70.4
16	77.8	77.3	76.3	76.6
32	82.3	82.1	81.2	81.4
128	92.5	90.4	90.4	90.6
512	97.2	97.2	97.2	98.1
1024	99.1	98.9	98.7	98.8
2048	100.0	100.0	100.0	100.0

Table XXII.—Temperature Coefficients.

V.	0° to 12°. ₂ .		12°. ₂ to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
2	2.59	2.68	2.93	2.29	3.18	1.92
8	3.35	3.00	3.45	2.27	3.94	2.01
16	3.74	3.17	3.90	2.39	4.25	1.99
32	4.04	3.24	4.17	2.40	4.48	1.97
128	4.18	2.98	4.82	2.52	5.01	1.98
512	4.78	3.24	5.19	2.53	5.44	2.00
1024	4.84	3.22	5.23	2.50	5.40	1.96
2048	4.93	3.26	5.34	2.52	5.44	1.94

*Potassium Dichromate.**Table XXIII.—Molecular Conductivity.*

V.	0°.	12° 6.	25°.	35°.
8	109.1	150.8	195.5	234.0
16	116.6	161.5	209.3	248.8
32	122.6	168.8	219.4	260.9
128	129.9	178.8	231.5	277.3
512	133.0	182.5	237.3	281.2
1024	133.6	185.7	240.6	287.9
2048	136.8	188.8	245.5	293.6

Table XXIV.—Percentage Dissociation.

V.	0°.	12° 6.	25°.	35°.
8	79.8	79.9	79.6	79.6
16	85.2	85.5	85.3	84.7
32	89.6	89.4	89.4	88.9
128	95.0	94.7	94.3	94.4
512	97.2	96.7	96.7	95.8
1024	97.7	98.4	98.0	98.1
2048	100.0	100.0	100.0	100.0

Table XXV.—Temperature Coefficients.

V.	0° to 12° 6.		12° 6 to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
8	3.31	3.03	3.60	2.19	3.85	1.97
16	3.56	3.05	3.85	2.38	3.95	1.89
32	3.66	2.98	4.08	2.42	4.15	1.89
128	3.88	2.99	4.25	2.38	4.39	1.90
512	3.93	2.95	4.42	2.42	4.45	1.88
1024	4.13	3.09	4.43	2.39	4.73	1.97
2048	4.13	3.02	4.57	2.42	4.81	1.96

*Calcium Nitrate.**Table XXVI.—Molecular Conductivity.*

V.	0°.	9°7.	25°.	35°.
2	65.84	85.83	121.0	145.0
8	85.50	112.8	157.3	188.2
16	94.95	123.9	174.2	209.8
32	102.3	133.5	187.7	225.6
128	114.5	151.0	212.0	255.4
512	122.6	160.6	226.7	274.2
1024	125.7	164.2	235.0	282.9
2048	130.0	171.4	242.7	292.4

Table XXVII.—Percentage Dissociation.

V.	0°.	9°7.	25°.	35°.
2	50.7	50.1	49.9	49.6
8	65.8	65.8	64.8	64.4
16	73.0	72.3	71.8	71.8
32	78.7	77.9	77.3	77.2
128	88.1	88.1	87.4	87.4
512	94.3	93.7	93.4	93.8
1024	96.7	95.8	96.8	96.8
2048	100.0	100.0	100.0	100.0

Table XXVIII.—Temperature Coefficients.

V.	0° to 9°7.		9°7 to 25°.		25° to 35°.	
	Cond. units.	Percent.	Cond. units.	Percent.	Cond. units.	Percent.
2	2.04	3.10	2.31	2.69	2.40	1.98
8	2.81	3.29	2.91	2.58	3.09	1.96
16	2.98	3.14	3.29	2.82	3.56	2.04
32	3.22	3.15	3.54	2.62	3.79	2.02
128	3.76	3.28	3.99	2.64	4.34	2.05
512	3.92	3.19	4.32	2.69	4.75	2.10
1024	4.01	3.19	4.60	2.80	4.79	2.04
2048	4.31	3.32	4.64	2.71	4.97	2.05

*Strontium Chloride.**Table XXIX.—Molecular Conductivity.*

V.	0°.	9°9.	25°.	35°.
2	81.36	106.2	141.5	172.0
8	92.97	124.3	173.7	207.4
16	101.1	134.5	187.7	225.9
32	106.3	141.5	198.4	238.7
128	118.5	157.6	225.0	271.6
512	125.0	166.1	236.7	285.4
1024	129.1	171.4	242.8	294.1
2048	133.9	176.1	248.7	300.3
4096	133.3	176.0	248.6	(303.9)

Table XXX.—Percentage Dissociation.

V.	0°.	9°9.	25°.	35°.
2	60.8	60.3	56.9	57.3
8	69.5	70.6	69.8	69.1
16	75.5	76.4	75.5	75.2
32	79.4	80.4	79.8	79.5
128	88.5	89.5	90.5	90.5
512	93.4	94.3	95.2	95.0
1024	96.4	97.3	97.6	97.9
2048	100.0	100.0	100.0	100.0
4096	100.0	100.0	100.0	100.0

Table XXXI.—Temperature Coefficients.

V.	0° to 9°9		9°9 to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
2	2.51	3.09	2.34	2.20	3.05	2.16
8	3.16	3.39	3.27	2.63	3.37	1.94
16	3.38	3.34	3.52	2.62	3.82	2.03
32	3.56	3.35	3.90	2.76	4.03	2.03
128	3.96	3.34	4.46	2.83	4.66	2.07
512	4.15	3.32	4.67	2.81	4.87	2.06
1024	4.27	3.31	4.73	2.76	5.13	2.11
2048	4.27	3.22	4.81	2.73	5.16	2.07
4096	4.31	3.23	4.81	2.73	5.31	2.14

*Strontium Nitrate.**Table XXXII.—Molecular Conductivity.*

V.	0°.	10°.	25°.	35°.
2	63.24	81.25	112.4	135.4
8	84.33	112.8	154.1	181.7
16	93.33	124.8	171.4	205.7
32	100.7	133.3	185.3	223.5
128	114.8	151.4	211.2	254.0
512	122.5	161.6	227.1	273.5
1024	126.9	167.0	233.7	282.3
2048	131.3	171.9	238.6	287.5

Table XXXIII.—Percentage Dissociation.

V.	0°.	10°.	25°.	35°.
2	48.2	47.3	47.1	47.1
8	64.2	65.5	64.6	63.2
16	71.1	72.6	71.8	71.5
32	77.7	77.5	77.7	77.7
128	87.4	88.1	88.5	88.4
512	93.3	94.0	95.2	95.1
1024	96.7	97.2	97.9	98.2
2048	100.0	100.0	100.0	100.0

Table XXXIV.—Temperature Coefficients.

V.	0° to 10°.		10° to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
2	1.80	2.85	2.07	2.55	2.30	2.05
8	2.85	3.38	2.75	2.44	2.76	1.79
16	3.14	3.36	3.11	2.49	3.43	2.00
32	3.26	3.24	3.47	2.60	3.82	2.06
128	3.66	3.19	3.99	2.63	4.28	2.03
512	3.91	3.19	4.37	2.70	4.64	2.04
1024	4.01	3.16	4.45	2.66	4.86	2.08
2048	4.06	3.10	4.45	2.59	4.89	2.05

*Strontium Formate.**Table XXXV.—Molecular Conductivity.*

V.	0°.	15°.5.	25°.	35°.
2	48.82	73.05	89.25	107.9
8	69.86	105.2	130.0	157.9
16	77.61	119.1	147.9	178.6
32	85.69	129.9	160.7	195.8
128	99.57	147.9	184.0	225.0
512	105.0	153.5	193.4	237.7
1024	109.0	168.6	209.0	254.1
2048	111.8	172.2	212.5	258.1

Table XXXVI.—Percentage Dissociation.

V.	0°.	15°.5.	25°.	35°.
2	43.7	42.4	42.0	41.8
8	62.5	61.1	61.2	61.1
16	69.4	69.0	69.6	69.2
32	76.6	75.4	75.6	75.9
128	89.1	85.9	86.6	87.2
512	93.9	89.2	91.0	92.1
1024	97.5	97.9	98.3	98.5
2048	100.0	100.0	100.0	100.0

Table XXXVII.—Temperature Coefficients.

V.	0° to 15°.5.		15°.5 to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
2	1.56	3.20	1.70	2.32	1.87	2.09
8	2.27	3.25	2.61	2.48	2.77	2.13
16	2.67	3.44	3.03	2.54	3.07	2.08
32	2.85	3.32	3.24	2.49	3.51	2.18
128	3.11	3.13	3.80	2.57	4.10	2.23
512	3.13	2.98	4.12	2.68	4.43	2.29
1024	3.84	3.52	4.25	2.52	4.49	2.24
2048	3.91	3.49	4.24	2.46	4.56	2.14

*Barium Bromide.**Table XXXVIII.—Molecular Conductivity.*

V.	0°.	10°.	25°.	35°.
2	91.81	119.3	158.6	188.1
8	103.4	137.0	187.4	224.0
16	109.3	144.8	198.9	238.8
32	114.4	151.0	209.4	251.4
128	123.6	163.7	228.5	274.4
512	131.8	175.5	246.8	298.2
1024	133.8	177.2	249.9	301.6
2048	134.2	178.7	252.6	305.7

Table XXXIX.—Percentage Dissociation.

V.	0°.	10°.	25°.	35°.
2	68.4	66.8	62.8	61.5
8	77.1	76.7	74.2	73.3
16	81.5	81.0	78.7	78.1
32	85.3	84.5	82.9	82.2
128	92.1	91.6	90.5	89.8
512	98.2	98.2	97.7	97.6
1024	99.7	99.2	98.9	98.7
2048	100.0	100.0	100.0	100.0

Table XL.—Temperature Coefficients.

V.	0° to 10°.		10° to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
2	2.74	2.98	2.62	2.20	2.95	1.86
8	3.36	3.25	3.36	2.45	3.66	1.95
16	3.55	3.25	3.60	2.49	3.99	2.01
32	3.66	3.20	3.89	2.58	4.20	2.01
128	4.01	3.24	4.32	2.64	4.59	2.01
512	4.37	3.32	4.75	2.71	5.14	2.08
1024	4.34	3.24	4.85	2.74	5.18	2.07
2048	4.45	3.32	4.93	2.76	5.24	2.07

*Barium Nitrate.**Table XLI.—Molecular Conductivity.*

V.	0°.	10°.	25°.	35°.
8	76.37	103.0	146.4	177.3
16	88.29	117.6	165.2	200.1
32	97.62	129.8	183.2	219.8
128	114.4	150.8	210.0	251.8
512	124.3	163.8	229.2	275.2
1024	127.4	167.8	234.2	281.6
2048	131.4	171.6	239.8	288.8

Table XLII.—Percentage Dissociation.

V.	0°.	10°.	25°.	35°.
8	58.1	60.0	61.1	61.4
16	67.2	68.5	68.9	69.3
32	74.3	75.6	76.4	76.1
128	87.1	87.9	87.6	87.2
512	94.6	95.5	95.6	95.3
1024	97.0	97.8	97.7	97.5
2048	100.0	100.0	100.0	100.0

Table XLIII.—Temperature Coefficients.

V.	0° to 10°.		10° to 25°.		25° to 35°.	
	Cond. units.	Percent.	Cond. units.	Percent.	Cond. units.	Percent.
8	2.66	3.48	2.89	2.81	3.09	2.11
16	2.93	3.32	3.17	2.70	3.49	2.11
32	3.22	3.30	3.56	2.74	3.66	2.00
128	3.64	3.18	3.95	2.62	4.18	1.99
512	3.95	3.18	4.36	2.66	4.60	2.01
1024	4.04	3.17	4.43	2.64	4.74	2.02
2048	4.02	3.06	4.55	2.65	4.90	2.04

*Barium Formate.**Table XLIV.—Molecular Conductivity.*

V.	0°.	10°.	25°.	35°.
2	51.67	67.74	93.97	112.1
8	72.22	95.34	133.4	159.2
16	77.72	102.7	144.6	173.8
32	85.56	114.3	160.6	193.1
128	86.20	114.3	162.4	197.4
512	102.2	133.6	182.0	215.2
1024	103.0	135.0	184.0	226.2
2048	111.8	149.4	210.0	257.6

Table XLV.—Percentage Dissociation.

V.	0°.	10°.	25°.	35°.
2	46.2	45.3	44.8	43.5
8	64.6	63.8	63.5	61.8
16	69.5	68.7	68.9	69.0
32	76.5	76.5	76.5	75.0
128	77.1	76.5	77.3	76.6
512	91.4	89.4	86.7	83.5
1024	92.1	90.3	87.7	87.8
2048	100.0	100.0	100.0	100.0

Table XLVI.—Temperature Coefficients.

V.	0° to 10°.		10° to 25°.		25° to 35°.	
	Cond. units.	Percent.	Cond. units.	Percent.	Cond. units.	Percent.
2	1.60	3.10	1.75	2.58	1.81	1.93
8	2.31	3.20	2.54	2.66	2.58	1.93
16	2.49	3.20	2.79	2.72	2.92	2.02
32	2.87	3.35	3.09	2.70	3.25	2.02
128	2.81	3.26	3.27	2.86	3.50	2.16
512	3.15	3.08	3.23	2.41	3.32	1.82
1024	3.20	3.10	3.33	2.46	4.22	2.29
2048	3.76	3.36	4.04	2.70	4.76	2.27

*Barium Acetate.**Table XLVII.—Molecular Conductivity.*

V.	0°.	10°.	25°.	35°.
2	40.16	53.25	76.18	89.95
8	59.05	79.46	113.3	136.0
16	65.68	87.10	124.3	149.3
32	72.93	97.58	139.5	168.6
128	78.15	104.5	149.0	181.2
512	90.75	123.1	176.9	215.8
1024	92.63	124.7	180.5	219.8
2048	95.96	129.3	186.3	226.7

Table XLVIII.—Percentage Dissociation.

V.	0°.	10°.	25°.	35°.
2	41.9	41.2	40.9	39.7
8	63.0	61.5	60.8	60.0
16	68.4	67.4	66.7	66.0
32	76.0	75.5	74.9	74.4
128	81.4	80.8	80.0	79.9
512	94.6	95.2	95.0	95.2
1024	96.5	96.4	96.9	97.0
2048	100.0	100.0	100.0	100.0

Table XLIX.—Temperature Coefficients.

V.	0° to 10°.		10° to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units	Per cent.	Cond. units.	Per cent
2	1.30	3.24	1.52	2.85	1.37	1.80
8	2.04	3.45	2.26	2.84	2.27	2.00
16	2.14	3.26	2.48	2.85	2.52	2.03
32	2.46	3.38	2.79	2.86	2.91	2.09
128	3.63	3.37	2.97	2.84	3.22	2.16
512	3.23	3.56	3.59	2.91	3.89	2.20
1024	3.20	3.45	3.72	2.98	3.93	2.18
2048	3.33	3.47	3.80	2.93	4.04	2.17

*Magnesium Sulphate.**Table L.—Molecular Conductivity.*

V.	0°.	10°.	25°.	35°.
2	32.12	43.14	60.57	72.68
8	45.70	60.90	85.62	102.4
16	50.95	68.14	96.50	115.0
32	59.57	79.73	112.4	135.3
128	71.17	95.38	135.9	164.4
512	95.57	128.3	183.3	221.9
1024	102.7	138.4	198.3	240.9
2048	111.1	148.5	215.2	261.0

Table LI.—Percentage Dissociation.

V.	0°.	10°.	25°.	35°.
2	28.9	29.1	28.2	27.8
8	41.1	41.0	39.8	39.2
16	45.9	45.9	44.8	44.1
32	53.6	53.7	52.2	51.8
128	64.1	64.2	63.2	63.0
512	86.0	84.4	85.2	85.0
1024	92.4	93.2	92.3	92.3
2048	100.0	100.0	100.0	100.0

Table LII.—Temperature Coefficients.

V.	0° to 10°.		10° to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
2	1.10	3.42	1.16	2.69	1.21	2.00
8	1.52	3.33	1.65	2.71	1.67	1.95
16	1.71	3.36	1.89	2.77	1.85	1.92
32	2.01	3.37	2.18	2.73	2.29	2.04
128	2.42	3.40	2.75	2.88	2.85	2.10
512	3.27	3.42	3.73	2.91	3.86	2.11
1024	3.57	3.48	3.99	2.88	4.26	2.15
2048	3.74	3.37	4.45	2.99	4.58	2.22

*Cupric Bromide.**Table LIII.—Molecular Conductivity.*

V.	0°.	13°.3.	25°.	35°.
2	75.27	103.9	135.3	156.1
8	91.31	131.0	169.6	203.8
16	99.30	141.4	183.0	220.3
32	105.0	149.8	194.3	234.1
128	118.2	169.0	220.0	266.0
512	122.2	177.3	230.8	278.4
1024	125.4	181.2	236.6	285.9
2048	131.4	187.5	242.7	295.0
4096	...	...	248.8	300.2
8192	...	...	274.8	325.1

Table LIV.—Percentage Dissociation.

V.	0°.	13°.3.	25°.	35°.
2	57.3	55.4	55.7	52.9
8	69.5	69.9	69.9	69.1
16	75.6	75.4	75.4	74.7
32	79.9	79.9	80.1	79.3
128	90.0	90.1	90.6	90.2
512	93.0	94.6	95.1	94.4
1024	95.4	96.6	97.5	96.9
2048	100.0	100.0	100.0	100.0

Table LV.—Temperature Coefficients.

V.	0° to 13°.3.		13°.3 to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
2	2.16	2.87	2.68	2.58	2.08	1.54
8	2.99	3.27	3.30	2.51	3.42	2.02
16	3.17	3.19	3.50	2.48	3.73	2.04
32	3.37	3.21	3.75	2.50	3.98	2.04
128	3.82	3.23	4.35	2.57	4.60	2.09
512	4.14	3.38	4.57	2.57	4.76	2.06
1024	4.19	3.34	4.73	2.61	4.93	2.08
2048	4.22	3.21	4.72	2.52	5.23	2.15
4096	..	..	..	..	5.14	..
8192	..	..	..	..	5.03	..

*Chromium Chloride.**Table LVI.—Molecular Conductivity.*

V.	0°.	10°.	25°.	35°.
8	116.3	153.7	216.9	261.7
16	128.7	171.1	243.0	294.5
32	137.5	184.2	262.9	319.9
128	152.6	204.5	297.0	365.3
512	190.6	260.8	384.0	475.4
1024	204.9	280.5	420.5	522.8
2048	214.6	294.3	441.7	553.4

Table LVII.—Percentage Dissociation.

V.	0°.	10°.	25°.	35°.
8	54.2	52.2	49.1	47.3
16	60.0	58.1	55.0	53.2
32	64.1	62.6	59.5	57.8
128	71.1	69.5	67.2	66.0
512	88.8	88.6	86.9	85.9
1024	95.5	95.3	95.2	94.5
2048	100.0	100.0	100.0	100.0

Table LVIII.—Temperature Coefficients.

V.	0° to 10°.		10° to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
8	3.74	3.30	4.21	2.74	4.48	2.07
16	4.24	3.29	4.79	2.80	5.15	2.12
32	4.67	3.40	5.25	2.85	5.70	2.17
128	5.19	3.40	6.17	3.35	6.83	2.29
512	7.02	3.68	8.21	3.15	9.14	2.30
1024	7.56	3.69	9.33	3.33	10.23	2.43
2048	7.97	3.71	9.83	3.34	11.17	2.53

*Chromium Nitrate.**Table LIX.—Molecular Conductivity.*

V.	0°.	10°.	25°.	35°.
2	87.17	112.1	154.7	183.6
8	117.6	153.1	214.0	256.5
16	129.7	169.7	238.8	287.4
32	138.5	181.9	258.1	312.6
128	149.0	198.9	286.2	350.7
512	188.7	253.0	370.2	459.4
1024	203.0	274.0	412.9	511.8
2048	210.4	295.3	438.0	550.9

Table LX.—Percentage Dissociation.

V.	0°.	10°.	25°.	35°.
2	41.4	38.0	35.3	33.3
8	55.9	51.9	48.9	46.6
16	61.6	57.5	54.5	52.2
32	65.8	61.8	58.9	56.8
128	70.8	67.4	65.3	63.7
512	89.7	85.7	84.5	83.6
1024	96.5	92.8	94.3	93.4
2048	100.0	100.0	100.0	100.0

Table LXI.—Temperature Coefficients.

V.	0° to 10°.		10° to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
2	2.49	2.86	2.84	2.53	2.89	1.87
8	3.55	3.02	4.06	2.65	4.25	1.99
16	4.00	3.08	4.61	2.72	4.86	2.04
32	4.34	3.13	5.08	2.79	5.45	2.11
128	4.99	3.35	5.82	2.93	6.45	2.25
512	6.43	3.41	7.81	3.09	8.92	2.41
1024	7.10	3.50	9.26	3.38	9.89	2.40
2048	8.49	4.04	9.51	3.22	11.29	2.58

*Ferric Chloride.**Table LXII.—Molecular Conductivity.*

V.	0°.	10°.	25°.	35°.
2	80.50	104.6	143.6	169.9
8	127.2	168.5	238.1	285.4
16	143.4	190.7	274.6	332.7
32	166.7	226.0	328.3	400.4
128	198.9	274.0	401.9	508.9
512	351.2	563.1	707.2	945.0
1024	486.3	688.4	892.4	1130.3
2048	609.7	799.9	1028.2	1235.6

Table LXIII.—Temperature Coefficients.

V.	0° to 10°.		10° to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
2	2.41	2.99	2.60	2.49	2.65	1.85
8	4.13	3.25	4.64	2.75	4.73	1.99
16	4.73	3.30	5.59	2.93	5.81	2.12
32	5.93	3.56	6.82	3.02	7.21	2.20
128	7.51	3.78	8.53	3.11	10.70	2.66
512	21.1	6.01	9.61	1.71	23.78	3.36
1024	20.2	4.15	13.66	1.98	23.60	2.64
2048	19.0	3.12	12.27	1.50	24.16	2.35

*Ferric Nitrate.**Table LXIV.—Molecular Conductivity.*

V.	0°.	10°.	25°.	35°.
2	97.68	128.1	181.6	220.7
8	138.2	185.7	266.5	328.2
16	150.7	202.7	295.3	364.3
32	171.4	233.7	342.6	422.6
128	199.5	271.7	399.4	491.4
512	371.3	408.7	705.7	927.0
1024	490.9	571.4	877.7	1116.5
2048	585.2	693.5	961.6	1183.0

Table LXV.—Temperature Coefficients.

V.	0° to 10°.		10° to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
2	3.04	3.12	3.57	2.79	3.91	2.15
8	4.75	3.44	5.39	2.90	6.17	2.32
16	5.20	3.44	6.17	3.04	6.90	2.34
32	6.23	3.63	7.26	3.11	8.00	2.34
128	7.22	3.62	8.50	3.13	9.20	2.30
512	3.74	1.01	19.80	4.84	22.13	3.14
1024	8.05	1.64	20.42	3.57	23.88	2.72
2048	10.83	1.85	18.61	2.68	22.14	2.30

*Nickel Sulphate.**Table LXVI.—Molecular Conductivity.*

V.	0°.	10°.	25°.	35°.
2	28.77	38.37	54.58	64.38
8	40.58	54.42	77.06	90.95
16	47.78	64.00	90.44	106.9
32	54.78	73.23	103.5	123.0
128	73.95	99.92	140.3	168.4
512	93.12	124.7	177.5	213.5
1024	100.4	134.8	193.8	234.6
2048	108.3	145.5	208.7	253.9

Table LXVII.—Percentage Dissociation.

V.	0°.	10°.	25°.	35°.
2	26.6	25.8	26.2	25.4
8	37.5	37.4	36.9	35.8
16	44.1	44.0	43.3	42.1
32	50.6	50.3	49.6	48.5
128	68.3	68.7	67.2	66.3
512	86.0	85.7	85.1	84.1
1024	92.7	92.6	92.9	92.4
2048	100.0	100.0	100.0	100.0

Table LXVIII.—Temperature Coefficients.

V.	0° to 10°.		10° to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
2	0.96	3.34	1.08	2.81	0.98	1.80
8	1.38	3.40	1.50	2.75	1.39	1.80
16	1.62	3.39	1.76	2.75	1.64	1.81
32	1.84	3.36	2.01	2.74	1.95	1.88
128	2.59	3.50	2.69	2.69	2.81	2.00
512	3.16	3.39	3.52	2.82	3.60	2.03
1024	3.44	3.43	3.93	2.91	4.08	2.11
2048	3.72	3.43	4.21	2.89	4.52	2.17

*Nickel Acetate.**Table LXIX.—Molecular Conductivity.*

V.	0°.	10°.	25°.	35°.
2	20.11	27.24	39.22	47.46
8	38.95	52.07	74.10	89.29
16	47.81	64.03	91.60	110.2
32	54.11	73.82	105.8	128.1
128	69.22	92.82	134.6	164.0
512	76.66	103.5	150.7	184.7
1024	78.65	105.9	153.9	189.1
2048	82.24	110.9	160.6	196.6

Table LXX.—Percentage Dissociation.

V.	0°.	10°.	25°.	35°.
2	24.5	24.6	24.4	24.1
8	47.4	47.0	45.1	45.4
16	56.8	57.7	57.0	56.1
32	65.8	66.6	65.9	65.2
128	84.2	83.7	83.8	83.4
512	93.2	93.3	93.8	93.9
1024	95.6	95.5	95.8	96.2
2048	100.0	100.0	100.0	100.0

Table LXXI.—Temperature Coefficients.

V.	0° to 10°.		10° to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
2	0.71	3.53	0.79	2.90	0.82	2.09
8	1.31	3.39	1.47	2.82	1.51	2.04
16	1.62	3.39	1.84	2.87	1.86	2.03
32	1.97	3.64	2.13	2.89	2.23	2.11
128	2.36	3.41	2.78	3.00	2.94	2.18
512	2.68	3.50	3.14	3.03	3.40	2.26
1024	2.72	3.46	3.20	3.02	3.52	2.29
2048	2.86	3.48	3.31	2.98	3.60	2.24

*Cobalt Sulphate.**Table LXXII.—Molecular Conductivity.*

V.	0°.	10°.	25°.	35°.
2	29.47	39.22	55.10	65.57
8	42.06	56.00	78.37	93.14
16	49.26	65.61	91.97	109.4
32	56.26	75.04	105.4	125.8
128	75.89	101.5	143.4	172.1
512	94.88	126.9	180.2	218.1
1024	101.9	137.6	196.9	239.2
2048	110.9	148.4	214.1	259.2

Table LXXIII.—Percentage Dissociation.

V.	0°.	10°.	25°.	35°.
2	26.6	26.4	25.7	25.3
8	37.9	37.7	36.6	35.9
16	44.4	44.2	43.0	42.2
32	50.7	50.6	49.2	48.5
128	68.4	68.4	67.0	66.4
512	85.6	85.5	84.2	84.2
1024	91.9	92.7	92.0	92.3
2048	100.0	100.0	100.0	100.0

Table LXXIV.—Temperature Coefficients.

V.	0° to 10°.		10° to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
2	0.97	3.29	1.06	2.70	1.04	1.89
8	1.39	3.30	1.49	2.66	1.47	1.88
16	1.63	3.31	1.76	2.68	1.74	1.89
32	1.88	3.34	2.02	2.69	2.04	1.94
128	2.56	3.37	2.79	2.75	2.87	2.00
512	3.21	3.38	3.55	2.79	3.79	2.10
1024	3.57	3.50	3.95	2.87	4.23	2.15
2048	3.75	3.38	4.38	2.95	4.51	2.11

*Cobalt Acetate.**Table LXXV.—Molecular Conductivity.*

V.	0°.	10°.	25°.	35°.
2	22.20	29.79	42.55	51.02
8	41.31	55.27	78.37	94.00
16	50.07	67.20	95.68	114.9
32	56.92	76.66	109.8	132.1
128	71.25	95.67	136.8	166.3
512	78.29	106.0	153.6	188.1
1024	78.88	107.1	155.3	189.8
2048	82.71	113.2	163.7	199.3

Table LXXVI.—Percentage Dissociation.

V.	0°.	10°.	25°.	35°.
2	26.8	26.3	26.0	25.6
8	50.0	48.8	47.9	46.1
16	60.5	59.4	58.5	57.7
32	68.8	67.7	67.1	66.3
128	86.1	84.5	83.6	83.4
512	94.7	93.6	93.8	94.4
1024	95.4	94.6	94.9	95.2
2048	100.0	100.0	100.0	100.0

Table LXXVII.—Temperature Coefficients.

V.	0° to 10°.		10° to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
2	0.75	3.37	0.85	2.85	0.87	2.04
8	1.39	3.36	1.54	2.79	1.56	1.99
16	1.71	3.42	1.90	2.83	1.92	2.01
32	1.97	3.46	2.21	2.88	2.23	2.03
128	2.44	3.42	2.74	2.86	2.95	2.16
512	2.77	3.54	3.15	2.97	3.45	2.25
1024	2.82	3.58	3.21	2.99	3.45	2.22
2048	3.05	3.69	3.37	2.98	3.56	2.17

*Lead Nitrate.**Table LXXVIII.—Molecular Conductivity.*

V.	0°.	10°.	25°.	35°.
2	46.30	63.55	92.68	113.0
8	71.12	97.32	139.8	169.5
16	84.43	113.3	161.5	195.6
32	93.85	128.3	181.5	118.8
128	115.1	153.1	214.0	256.7
512	129.1	171.9	238.3	287.1
1024	133.6	178.1	247.4	297.5
2048	135.1	178.7	247.2	299.0

Table LXXIX.—Percentage Dissociation.

V.	0°.	10°.	25°.	35°.
2	34.3	35.6	37.5	37.8
8	52.6	54.5	55.3	56.7
16	62.5	63.4	65.3	65.4
32	69.5	71.8	73.4	73.2
128	85.2	85.7	86.6	85.9
512	95.6	96.2	96.4	96.0
1024	98.9	99.7	100.0	99.5
2048	100.0	100.0	100.0	100.0

Table LXXX.—Temperature Coefficients.

V.	0° to 10°.		10° to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
2	1.72	3.71	1.94	3.05	2.03	2.19
8	2.62	3.68	2.83	2.91	2.97	2.12
16	2.88	3.41	3.21	2.83	3.41	2.11
32	3.44	3.67	3.55	2.77	3.73	2.05
128	3.80	3.30	4.06	2.65	4.27	2.00
512	4.28	3.32	4.43	2.58	4.88	2.05
1024	4.45	3.33	4.62	2.59	5.01	2.03
2048	4.36	3.23	4.57	2.55	5.18	2.10

*Trichloroacetic Acid.**Table LXXXI.—Molecular Conductivity.*

V.	0°.	10°.	25°.	35°.
2	161.3	198.8	250.1	279.7
8	194.0	241.6	305.3	346.5
16	204.6	252.6	320.6	363.8
32	210.5	260.2	332.4	377.8
128	215.5	268.4	343.5	391.3
512	221.2	275.5	350.7	400.2
1024	220.3	272.6	350.4	399.3
2048	217.4	272.9	347.0	396.7

Table LXXXII.—Percentage Dissociation.

V.	0°.	10°.	25°.	35°.
2	72.9	72.2	71.3	69.9
8	87.7	87.7	87.1	86.6
16	92.5	91.7	91.4	90.9
32	95.5	94.5	94.8	94.4
128	97.4	97.4	97.9	97.8
512	100.0	100.0	100.0	100.0
1024	100.0	100.0	100.0	100.0
2048	100.0	100.0	100.0	100.0

Table LXXXIII.—Temperature Coefficients.

V.	0° to 10°.		10° to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
2	3.75	2.32	3.42	1.72	2.96	1.18
8	4.76	2.45	4.25	1.76	4.12	1.35
16	4.80	2.35	4.53	1.79	4.32	1.35
32	4.97	2.36	4.81	1.85	4.54	1.37
128	5.29	2.45	5.00	1.86	4.78	1.39
512	5.43	2.45	5.01	1.82	4.95	1.41
1024	5.23	2.37	5.24	1.92	4.89	1.40
2048	5.55	2.55	4.94	1.81	4.97	1.43

*Racemic Acid.**Table LXXXIV.—Molecular Conductivity.*

V.	0°.	15°.	25°.	35°.
2	8.77	12.60	15.19	17.54
8	17.87	25.70	30.89	35.65
16	24.72	35.64	42.89	49.46
32	34.04	49.17	59.02	68.18
128	62.32	90.59	108.4	124.8
512	109.0	155.0	184.4	212.5
1024	134.7	190.0	220.6	247.3
2048	169.5	238.3	290.9	336.7

Table LXXXV.—Percentage Dissociation.

V.	0°.	15°.	25°.	35°.
2	4.23	4.32	4.27	4.26
8	6.61	8.80	8.68	8.65
16	11.9	12.2	12.1	12.0
32	16.4	16.8	16.6	16.6
128	30.2	31.0	30.5	30.3
512	52.5	53.1	51.8	51.6
1024	64.9	65.1	62.0	60.0
2048	81.7	81.6	81.7	81.7

Table LXXXVI.—Temperature Coefficients.

V.	0° to 15°.		15° to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
2	0.26	2.91	0.26	2.06	0.24	1.55
8	0.52	2.92	0.52	2.02	0.48	1.54
16	0.73	2.94	0.73	2.03	0.66	1.53
32	1.01	2.97	0.99	2.00	0.92	1.55
128	1.88	3.02	1.78	1.97	1.64	1.51
512	3.07	2.82	2.94	1.89	2.81	1.52
1024	3.69	2.74	3.06	1.61	2.67	1.21
2048	4.59	2.71	5.26	2.21	4.58	1.57

*Picric Acid.**Table LXXXVII.—Molecular Conductivity.*

V.	0°.	15°.	25°.	35°.
32	193.0	260.2	303.7	345.1
128	201.1	272.4	319.9	365.2
512	207.6	280.9	329.6	377.5
1024	206.9	281.7	332.6	379.9
2048	205.5	277.1	325.6	372.7

Table LXXXVIII.—Percentage Dissociation.

V.	0°.	15°.	25°.	35°.
32	93.0	92.4	91.3	90.8
128	96.9	96.7	96.2	96.1
512	100.0	99.7	99.1	99.4
1024	100.0	100.0	100.0	100.0
2048	100.0	100.0	100.0	100.0

Table LXXXIX.—Temperature Coefficients.

V.	0° to 15°.		15° to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
32	4.48	2.32	4.35	1.67	4.14	1.36
128	4.75	2.36	4.75	1.77	4.53	1.42
512	4.89	2.36	4.87	1.73	4.79	1.42
1024	4.99	2.41	4.89	1.74	4.93	1.48
2048	4.73	2.30	4.85	1.75	4.71	1.45

*Propionic Acid.**Table XC.—Molecular Conductivity.*

V.	0°.	15°.	25°.	35°.
2	1.06	1.49	1.74	1.98
8	2.31	3.19	3.72	4.22
16	3.26	4.51	5.29	5.99
32	4.65	6.42	7.52	8.49
128	9.09	12.53	14.78	16.69
512	17.18	23.45	27.39	30.70
1024	23.49	32.09	37.58	42.29
2048	31.51	42.88	51.04	56.80

Table XCI.—Percentage Dissociation.

V.	0°.	15°.	25°.	35°.
2	0.48	0.49	0.49	0.49
8	1.04	1.06	1.04	1.06
16	1.47	1.50	1.47	1.50
32	2.10	2.12	2.09	2.13
128	4.10	4.15	4.12	4.18
512	7.74	7.77	7.63	7.69
1024	10.6	10.6	10.5	10.6
2048	14.2	14.2	14.2	14.2

Table XCII.—Temperature Coefficients.

V.	0° to 15°.		15° to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
2	0.03	2.64	0.03	1.68	0.02	1.32
8	0.05	2.25	0.05	1.66	0.05	1.31
16	0.08	2.55	0.08	1.70	0.07	1.32
32	0.12	2.54	0.11	1.71	0.10	1.29
128	0.23	2.52	0.23	1.80	0.19	1.29
512	0.42	2.43	0.39	1.68	0.33	1.21
1024	0.57	2.43	0.55	1.71	0.47	1.25
2048	0.76	2.41	0.82	1.90	0.58	1.13

o-Nitrobenzoic Acid.

Table XCIII.—Molecular Conductivity.

V.	0°.	15°.	25°.	35°.
32	98.15	120.5	132.2	140.6
128	146.9	184.9	205.6	222.6
512	187.5	244.1	278.3	307.8
1024	196.3	261.7	301.8	336.9
2048	200.8	267.4	312.2	351.8

Table XCIV.—Percentage Dissociation.

V.	0°.	15°.	25°.	35°.
32	43.1	39.6	37.2	35.2
128	64.4	60.8	57.9	55.7
512	82.2	80.3	78.4	77.0
1024	86.1	86.1	85.0	84.2
2048	88.1	88.0	88.0	88.0

Table XCV.—Temperature Coefficients.

V.	0° to 15°.		15° to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
32	1.49	1.52	1.17	0.97	0.84	0.59
128	2.53	1.72	2.07	1.12	1.70	0.76
512	3.77	2.61	3.42	1.40	2.95	1.06
1024	4.36	2.22	4.01	1.53	3.51	1.16
2048	4.44	2.21	4.48	1.68	3.96	1.27

m-Nitrobenzoic Acid.

Table XCVI.—Molecular Conductivity.

V.	0°.	15°.	25°.	35°.
128	40.10	56.85	67.66	77.56
512	71.95	101.0	120.0	137.1
1024	92.44	129.8	153.8	175.4
2048	115.1	160.7	190.5	216.7

Table XCVII.—Percentage Dissociation.

V.	0°.	15°.	25°.	35°.
128	18.7	19.0	19.1	19.2
512	33.6	33.8	33.8	33.9
1024	43.1	43.4	43.3	43.4
2048	53.7	53.8	53.7	53.6

Table XCVIII.—Temperature Coefficients.

V.	0° to 15°.		15° to 25°.		25° to 35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
128	1.12	2.79	1.08	1.90	0.99	1.46
512	1.87	2.60	1.90	1.88	1.71	1.43
1024	2.49	2.69	2.40	1.85	2.16	1.40
2048	3.04	2.64	2.98	1.85	2.62	1.38

Discussion of Results.

We have already shown that widely different conclusions have been reached regarding the effect of temperature on the conductivity and ionization of electrolytes in aqueous solution.

For the purpose of arriving at something definite it was desirable to extend the work to as many different compounds as possible. The present investigation includes twenty-eight inorganic salts and six organic acids. The salts were so chosen as to have a wide range of physical and chemical properties, especially those of valence and the power to crystallize with water of crystallization.

By glancing at any one of the preceding tables it will be seen that the molecular conductivity of electrolytes increases with rise in temperature from 0° to 35°; that conductivity increases with increase in dilution up to a certain maximum

value, and that dissociation increases with increase in dilution up to the point where the electrolyte is completely dissociated. These facts are, however, so well established by previous work that additional evidence seems almost unnecessary.

A maximum in the conductivity curve, as described by Sack,¹ Kohlrausch,² Noyes,³ and others, was not observed at

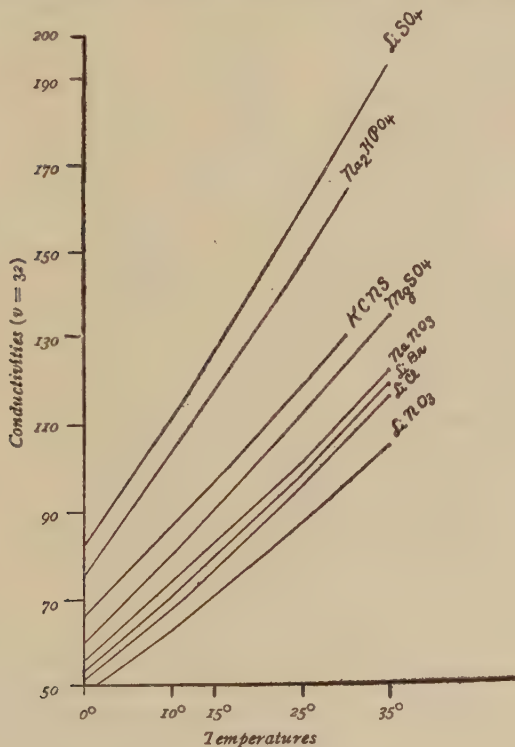


Fig. III.

any time during the progress of the work. This however, was not to be expected, since a maximum conductivity generally occurs at much higher temperatures than those at which I worked.

With these preliminary observations we shall turn to the

¹ Wied. Ann., 43, 212 (1891).

² Pogg. Ann., 154, 215 (1875).

³ J. Am. Chem. Soc., 26, 134 (1904).

real questions at issue. In the first place: Is conductivity a linear function of the temperature? As is pointed out in the introduction, different conclusions have been reached by different experimenters. My work goes to show that, except in the case of water, *conductivity is not a linear function of the temperature at any dilution with which I worked.* The increase in conductivity with rise in temperature is greater

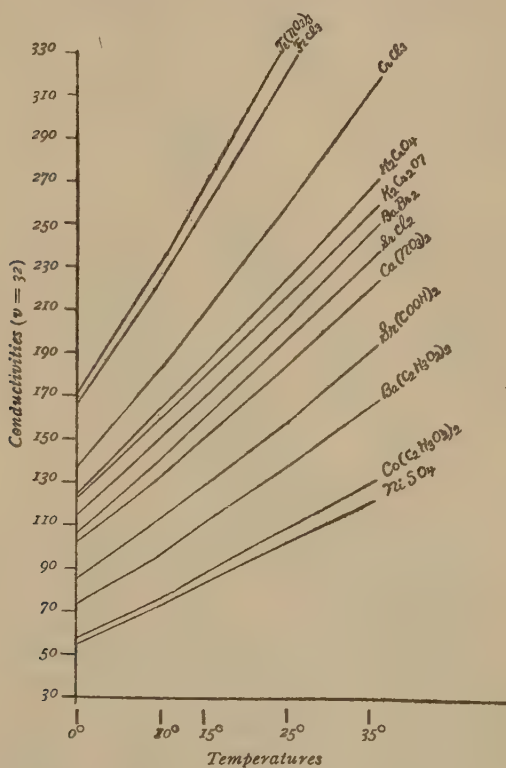


Fig. IV.

the higher the temperature. This becomes more apparent by observing the curves in Figs. III, IV, and V, where molecular conductivities are the ordinates and temperatures the abscissae. Water presents the only exception to this rule. In Fig. II the conductivity of water has been plotted against temperature, and as is seen the relation is a linear one from 0° to 35°.

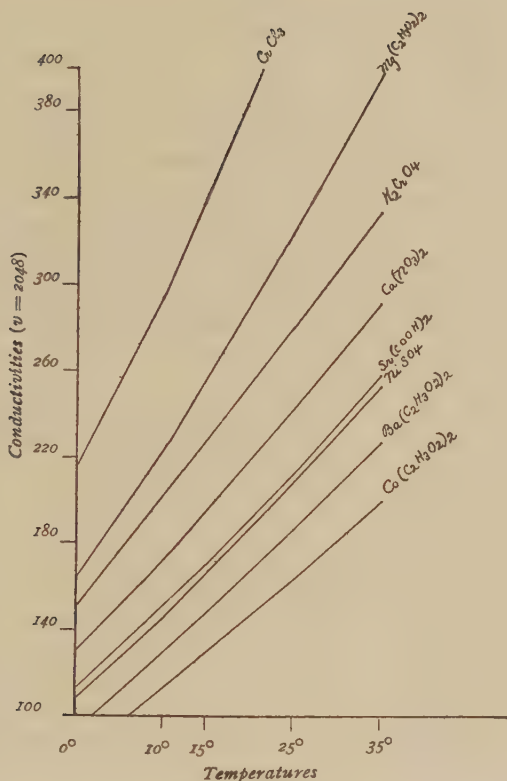


Fig. V.

The increase in the conductivity of electrolytes with rise^v in temperature is undoubtedly due, as has been pointed out by Jones,¹ largely to the fact that all electrolytes in aqueous solution are hydrated to a greater or less extent, and that rise in temperature diminishes the extent of this hydration. It is clear that when the ions become partly or wholly freed from the water attached to them, their mass, and probably their size, will be reduced. This will allow them to move through the solution with less friction and, consequently, increase the conductivity. Therefore, it is fair to conclude that the conductivity of those ions which are hydrated to the greatest

¹ Am. Chem. Jour., **35**, 445 (1905).

extent in solution would be most affected by change in temperature. All of the experimental data, here given, support this conclusion.

In Table XCIX. is given a list of the substances investigated. They are arranged in the order of their increasing temperature coefficients. By referring to these tables it will be seen that those substances with little or no hydrating power are at the top, while those possessing a marked hydrating power appear towards the bottom of the list. Upon this hypothesis we may explain the fact that the change in conductivity with temperature is not a linear function in the case of ordinary electrolytes, while in the case of water it is a linear function.

Table XCIX.

Substance.	Temp. Coef., 0°-10°. $V=2048$.	Temp. Coef., 25°-35°. $V=2048$.
Lithium nitrate	1.76	2.07
Lithium chloride	1.92	2.31
Lithium bromide	1.94	2.34
Sodium nitrate	2.27	2.44
Potassium sulphocyanate	2.24	2.72
Nickel acetate	2.86	3.60
Cobalt acetate	3.03	3.56
Cobalt sulphate	3.75	4.51
Nickel sulphate	3.72	4.52
Barium acetate	3.33	4.04
Strontium formate	3.91	4.56
Disodium phosphate	3.68	4.44
Barium formate	3.76	4.76
Magnesium sulphate	3.74	4.58
Lithium sulphate	3.77	4.85
Potassium dichromate	4.13	4.81
Potassium chromate	4.93	5.44
Calcium nitrate	4.31	4.97
Strontium chloride	4.31	5.31
Cupric bromide	4.22	5.23
Barium bromide	4.45	5.24
Barium nitrate	4.02	4.90
Strontium nitrate	4.06	4.89
Lead nitrate	4.36	5.18
Chromium chloride	7.97	11.17
Chromium nitrate	8.49	11.29
Ferric nitrate	10.83	22.14
Ferric chloride	19.00	24.16

As has just been pointed out, the electrolytes whose ions are hydrated in solution will show a large increase in conductivity with rise in temperature. This is equivalent to saying that their conductivities are parabolic functions of the temperature. In the case of water it is difficult to see how the hydrogen or hydroxyl ions could become appreciably hydrated; and the fact that the conductivity of water increases regularly with rise in temperature goes to show that no such hydration exists, but that the increase in conductivity is conditioned chiefly by a change in the viscosity of the medium. This latter phenomenon we know to be a linear one with respect to temperature, and by *a priori* reasoning we would conclude that the conductivity of water, or of any entirely unhydrated electrolyte, if such existed, would also be a linear function of the temperature. Facts and theory are in perfect accord on this point.

Another factor, playing an important rôle in conductivity work, is hydrolysis. Scarcely too great emphasis can be laid on the fact that water is decomposed in the presence of a large number of substances in solution, and yet it is surprising to see how much conductivity work has been done where this fact has been overlooked or disregarded.

To ascertain the effect of hydrolysis on the conductivity of strongly hydrolyzed salts, we have included iron and chromium compounds in this work. By referring to the tables where the molecular conductivities of these compounds are given, it is seen that the increase in their conductivities at high dilutions is so abnormally large that one might think nothing but gross experimental error could account for it. It is also seen that their conductivities are disproportionately larger at higher temperatures. These results plainly show that hydrolysis is enormously increased with rise in temperature. Now the question arises: Is hydrolysis manifested only by salts of strong acids and weak bases, and *vice versa*, or where both acid and base are weak; or is it a phenomenon common to all electrolytes? The latter view is the one held by Ciamician,¹ Euler,² Bauer,³ and others. In order to obtain

¹ Z. physik. Chem., **6**, 403 (1890).

² *Ibid.*, **21**, 257 (1896).

³ *Ibid.*, **23**, 409 (1897).

evidence on this point let us again turn to the preceding tables. It is seen that in nearly every case the conductivity changes more or less suddenly from $V = 1024$ to $V = 2048$. The conductivity is by no means a constant at those dilutions, yet in the majority of cases the substances are thought to be completely dissociated. For these reasons we are convinced that nearly all, if not all, electrolytes are hydrolyzed in dilute solution.

Granting this fact, how would it affect the percentage dissociation as calculated by the formula: μ_v/μ_∞ ? It is clear that if hydrolysis takes place at high dilutions the value of μ_∞ as found is too large by that amount. For this reason α becomes smaller than it otherwise would. It is a well-known fact that hydrolysis is greatly accelerated by rise in temperature, and, consequently, the values for μ_∞ will grow proportionately larger as the temperature is raised. This will, of course, diminish the calculated value of the dissociation more and more the higher the temperature.

The above reasoning is based on the assumption that hydrolysis takes place to a greater extent in dilute than in more concentrated solutions. In case of weakly hydrolyzed compounds we should say that this is the case, for mass action then comes into play; whereas, with strongly hydrolyzed salts like the iron, lead, and aluminium compounds, the effect of hydrolysis would probably be more pronounced before high dilutions are reached. Referring to the tables of the iron salts we see that this theory is supported by the facts.

A summary of the results of the effect of rise in temperature on dissociation is given in Table C.

It is seen that the results are of the same general character as those obtained by Jones and West.¹ The fact that an increase in dissociation with rise in temperature is found with the iron salts, lead nitrate, and *m*-nitrobenzoic acid is doubtless due to hydrolysis, as is explained above.

For the reasons already mentioned it seems to me that the true effect of temperature on dissociation cannot be rigidly ascertained unless hydration, on the one hand, and hydrolysis,

¹ Am. Chem. Jour., **34**, 357 (1905).

Table C.

 α decreases with rise in temperature.

Potassium sulphocyanate
 Barium bromide
 " formate
 Sodium nitrate
 Disodium phosphate
 Lithium nitrate
 " chloride
 " bromide
 " sulphate
 Calcium nitrate
 Strontium formate
 Magnesium sulphate
 Nickel " "
 Cobalt " "
 Chromium chloride
 " nitrate
 Trichloroacetic acid
 Picric acid
 o-Nitrobenzoic acid

 α increases with rise in temperature.

Ferric chloride
 " nitrate
 Lead nitrate
 m-Nitrobenzoic acid

 α independent of temperature.

Potassium chromate
 Potassium dichromate
 Cupric bromide
 Racemic acid
 Propionic acid

 α decreases in concentrated, but increases in dilute solutions.

Barium acetate
 Cobalt " "
 Nickel " "

 α increases slightly in dilute solutions.

Strontium chloride
 " nitrate
 Barium " "

on the other, are taken into account. It is a fact, however, that many electrolytes are affected only to a relatively small extent by these influences, and that the value for dissociation calculated without taking them into account is not far from the correct one.

When we examine the temperature coefficients expressed in conductivity units, we find that, without exception, they increase as dilution increases, and for every salt they increase with rise in temperature; but the organic acids, on the other hand, have decreasing temperature coefficients with rise in temperature. This is more clearly seen by reference to Fig. 6, where coefficients are the ordinates and temperatures the abscissae.

The temperature coefficients expressed in percentages, on the other hand, invariably decrease with rise in temperature. The fact that temperature coefficients of all salts increase with rise in temperature, whereas both organic and inorganic acids have decreasing temperature coefficients, is easily explained

by the hydrate theory of Jones. The metallic cations are probably the ones that are chiefly hydrated in solution, and when the temperature is raised this hydration is diminished, thus greatly increasing the ionic mobility, while no such increase is possible where metallic ions are absent.

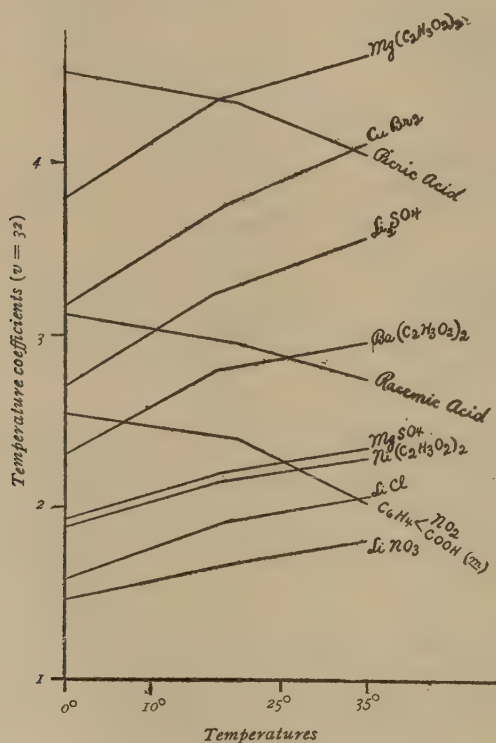


Fig. VI.

During the progress of this work I noticed a striking phenomenon in the telephone that should be mentioned. A short time after the circuit was closed, thus allowing the current to pass through the cell containing the electrolyte, a sudden increase in the loudness of the tone was noticed when the key was held near the node on the bridge. This phenomenon was at first thought to be due to polarization, but later,

when the same effect could be obtained with any solution, even with redistilled water, and since no noticeable change in conductivity could be detected as a result of it, I concluded that this phenomenon is novel in character, and as far as I know has not been described before. The time for this loudness to come on varied from a few seconds to eight or ten minutes, depending upon the nature of the electrolyte.

It is futile to speculate what might be its cause until more experimental evidence is obtained. One suggestion that might have an element of truth in it is the following: The kinetic vibrations of the ions may be influenced by the electrical stress, set up within the solution, in such a way that they will be brought to take place in the direction of the lines of force present. This idea could be illustrated by the molecular arrangement thought to exist in a permanent magnet.

Conclusions.

The following points have been verified or established by the present work:

1. The molecular conductivity of electrolytes in aqueous solution increases as a parabolic function of the temperature from 0° to 35°.
2. Conductivity increases with increase in dilution.
3. With increase in dilution dissociation increases up to a maximum value where it is complete.
4. Hydrolysis is a formidable source of error in obtaining the true value for μ_{∞} and consequently, in obtaining the true dissociation.
5. Disregarding the effect of hydrolysis, dissociation decreases with rise in temperature.
6. The conductivity of water is a linear function of the temperature.
7. Salts that are strongly hydrated in solution show a greater increase in conductivity with rise in temperature than the salts that are slightly hydrated.
8. The temperature coefficients, expressed in conductivity units, increase with rise in temperature. Those of the organic acids are exceptions.

9. The temperature coefficients expressed in percentages decrease with rise in temperature.

10. The temperature coefficients of compounds with similar properties vary in a similar manner with change in temperature.

BIOGRAPHY.

The author of this dissertation, Carl Alfred Jacobson, was born in Wood Lake, Wisconsin, January 25, 1876. His early education was received in the public schools of that place. During the years 1894-1896 he was engaged as public school teacher in the District Schools of Burnett County Wisconsin. In the fall of 1896 he entered Carleton Academy at Northfield, Minnesota, and two years later Carleton College at the same place. The year 1901-1902 he spent in Germany and Great Britain.

The degree of Bachelor of Science was granted him by Carleton College in 1903 and the degree of Master of Science in 1907. In the fall of 1903 he entered Johns Hopkins University as a graduate student in chemistry. The following three years he was engaged as instructor in chemistry and physiology in the High School at York, Pennsylvania. In the fall of 1907 he re-entered Johns Hopkins University where he has made chemistry the principal subject and has taken Physical Chemistry and Physics as subordinates.

